ARMY RESEARCH LABORATORY

Validation of the Atmospheric Transmission Large-Area Analysis System (ATLAS)

by Max P. Bleiweiss

ARL-TR-544

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13. ABSTRACT *(Maximum 200 words)*

The Atmospheric Transmission Large-Area Analysis System (ATLAS) is a unique tool that has been under development at the U.S. Army Research Laboratory since the mid-1980's. ATLAS is a nonintrusive, passive technique capable of producing two-dimensional transmittance maps of a smoke cloud in a plane perpendicular to the main-optical-axis line of sight (LOS). (Off-axis LOSs are not perpendicular but are in a fan with an angular intersect determined by the overall field of view of the imager.) (The accuracy and precision of the transmission values depends on the test conditions during which the measurements are made but can be defined through the error analyses discussed in this report. The spatial resolution of the resulting transmission maps is is also test specific, but, typically, is of the order of a few tens of centimeters. The temporal resolution is determined by the video rates of the imaging system, which, after preliminary low-pass filtering, yields maps at 10 Hz.) ATLAS is at the stage of development that it is used on a regular basis to support smoke/obscurant field tests. For this reason, a validation process was defined and implemented in 1989. This report documents the completion of that effort as a major milestone for the laboratory during FY92. In addition, the capabilities and limitations of the ATLAS technique are discussed in detail.

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1. Introduction

The Atmospheric Transmission Large-Area Analysis System (ATLAS) is a nonintrusive, passive technique in which two-dimensional transmittance maps of a smoke cloud in a plane perpendicular to the line of sight (LOS) are produced. (Off-axis LOSs are not perpendicular but are in a fan with the apex at the imager; however, because of the geometry, the approximation is not too far wrong.) Generally, ATLAS is a technique that uses an imager as a receiver and the natural background scene radiance or targets of opportunity* as the source to form a transmissometer system. Figure 1 is a schematic of the process. Typically, the background scene radiance, prior to the presence of smoke, is recorded and saved for comparison to the scene when smoke is present. Through a variety of algorithms, the cloud radiance under optically thick conditions is determined and, along with the processing of the two scenes (clear air and with aerosol present), yields a transmittance map. The advantage in using ATLAS over conventional techniques is its passive, nonintrusive capability and ability to measure the whole scene as opposed to a single LOS. A traditional transmissometer only samples the equivalence of a single pixel in a scene, whereas, ATLAS samples $\approx$ 200 X 200 pixels (the image array size). For typical test scenarios, this yields spatial resolution for the transmittance field of the order of a few tens of centimeters; if desired, it could be as small as a few centimeters. The temporal resolution is determined by the video rates of the imaging systems being used (30 frames/s; low-pass filtered to yield data at 10 Hz). A disadvantage of the current instrumentation setup is that the precision of the transmittance measurements determined by ATLAS is a few percent, because of low dynamic range. More conventional systems can measure transmittance levels of fractions of a percent. When there is insufficient natural scene radiance or targets of opportunity for determining transmittance, it is possible to place sources in the field of view and use the imager as the receiver and retain a certain degree of versatility. This latter mode can also be used for measurements in other portions of the spectrum

*A "target of opportunity," as used in this report, is defined as a localized region of the image that is considerably hotter than the surrounding background. The target of opportunity may be caused by a natural or cultural feature that appears hotter.

(visible, near-infrared (IR)) where scattering may dominate and the ATLAS algorithm is no longer valid.

ATLAS provides two-dimensional transmittance through the cloud so the full vertical and horizontal extent of the cloud, relative to its screening characteristics, can be determined. ATLAS can also assess impossible LOSs (elevated platform (slant path) or other horizontal LOSs not amenable to instrumentation) that would otherwise be inaccessible to measurement. Another ATLAS utility characterizes diffusion and transport processes to a degree not previously attained.* [1] In addition, the creation of a library of real smoke clouds for use in simulations/simulators is just being realized. [2] It is only with ATLAS that such measurements and tools are available.†

Because of the importance of the products of ATLAS processing, and as with any measurement technique, it is necessary to document the capabilities and limitations of the process. This effort is described in this report as a validation effort. This report describes the validation process used on ATLAS and the progress and results of the validation. It is to be understood that the validation process is an evolving and continual process as is the ATLAS technique itself. The progress with the ATLAS technique will develop as it is used and as new situations requiring its use become known.

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*Cloud 8904 was been supplied in part to, and is being used by, the developers of the Battlefield Environment Weather Simulation System. [3]

†This statement is valid because there are no other systems capable of freezing the cloud; for example, LIDAR systems require pulse rates of the order of tens of kHz to sample the cloud rapidly enough to ensure no significant cloud movement during the measurement period; such systems do not exist.

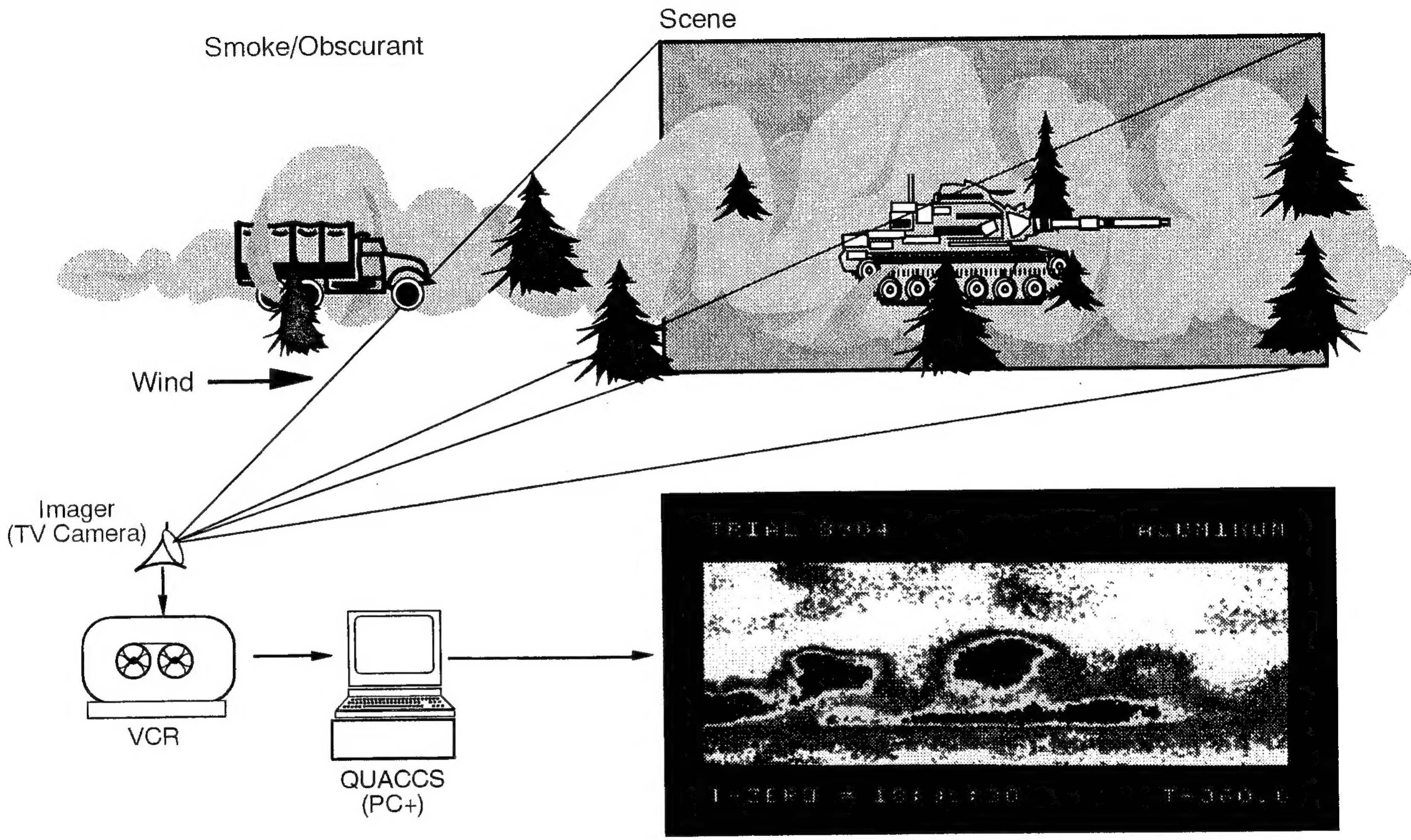

Figure 1. The ATLAS process shown schematically. The scene, containing a variety of natural and manmade objects, is imaged before and during the presence of smoke. The images, acquired with a thermal imager, are recorded to video tape for later data reduction that is accomplished with a pc-based image processing system.

2. Validation Process

The starting place for the validation process is analyses of the physics used in the ATLAS technique. For the physics, it was required that a detailed assessment be made of the radiative transfer process. As part of the assessment, it was necessary to determine the assumptions that were being made with the ATLAS algorithm and to define the limitations imposed on the process by those assumptions. Error analyses were performed and implemented because an important part of a validation procedure is knowing the errors of the measurement. The mitigation efforts that might be imposed to alleviate the limitations of ATLAS and ensure that the remaining assumptions are being addressed are discussed. The bulk of the analytical part of the validation process was carried out by Vonder Haar and associates at Colorado State University (CSU) and Metsat, Inc. These findings were presented in a series of reports and a symposium proceeding. [4,5,6,7] Empirical assessment was accomplished within the work unit and continues to advance with every new test; the efforts were presented at several symposia. [6,8,9]

2.1 Physics

The equation of radiative transfer (band-averaged) is given in equation (1):

$$N_R = N_C e^{-\tau} + (1-\omega)(1-e^{-\tau})B + \omega(1-e^{-\tau})N_e \tag{1}$$

where

N_c = the clear air radiance of background scene element
B = the Planck blackbody function of the cloud (cloud radiance)
N_e = the environmental radiation that scatters off the cloud
τ = the optical depth
ω = the single scattering albedo

Because it is not practical to measure or know all the terms for ATLAS processing, assumptions concerning the relative importance of the various quantities must be made.

2.2 Assumptions

Because the measurements made during ATLAS data acquisition are in the far-IR portion of the electromagnetic spectrum, the following assumptions can be made to make the analyses more tractable:

1. A single scattering of background radiance is through the cloud; otherwise, the extinction involves multiple scattering that cannot be accounted for in the algorithm used for ATLAS processing.

2. The scattering portion of the extinction coefficient is small.

3. The background radiance is temporally constant.

4. The background radiance is sufficiently different from the cloud radiance.

5. The grey level is proportional to radiance.

6. Aerosol is at ambient temperature and the cloud is the same temperature everywhere, which implies that the cloud radiance is the same everywhere*.

7. The presence of smoke does not significantly affect the characteristics of the ambient clear atmosphere.

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*Although the temperature in the atmosphere varies with height, no difference in cloud radiance with position in the cloud was detected, which could be ascribed to variable air temperature (this has not been formally documented).

The application of these assumptions allows equation (1) to be abbreviated to

$$N_R = N_C e^{-\tau} + (1-e^{-\tau})B \tag{2}$$

or, rearranging,

$$T = \frac{N_R - B}{N_C - B} \tag{3}$$

where

$$T = e^{-\tau}, \tag{4}$$

which is what ATLAS measures, and B becomes the limiting cloud radiance under optically thick ($\tau \rightarrow \infty$) conditions.

2.3 Limitations

Ensuring that the assumptions are valid during the measurement process requires that limitations be placed on the use of the ATLAS technique. The limitations of the technique appear when the assumptions are no longer valid, and in fact, new assumptions are discovered as new limitations appear. ATLAS is not a cure-all and does not work in all instances; therefore, as it is used, new limitations will surface. The current inventory of major limitations consists of the following:

1. Unless the background scene radiance is much different from the cloud grey level, a measurement at that pixel location cannot be made, which can place holes in the data and make large regions of the image not available for analyses. The *a priori* determination of acceptable versus unacceptable test conditions is yet to be accomplished with certainty and laid down as a set of rules for test conduct.

2. Along with the first limitation, not only does the scene radiance need to be different from the cloud grey level, but it needs to be sufficiently different to allow meaningful measurements; the quantification of the required difference, *a priori*, remains to be accomplished. However, the

application of the error analyses algorithm allows the customer to select this parameter based on the error in the measurements, which is acceptable.

3. To use the ATLAS algorithm, the cloud grey level must be known. Usually, a target of opportunity coupled with a nearby background scene element can be used to arrive at that number. If there are no such hot spots, the analyses cannot proceed. Another way to get at the cloud grey level is to have a transmissometer along an LOS in the field of view, which is not always possible. Until a reliable, nonintrusive technique for determining cloud grey level is developed, determining cloud grey level will be a major limitation on processing of ATLAS data. This limitation is the primary reason real-time ATLAS is not successful; the tools (hardware and software) are there to process the images, etc. but not the *a priori* determination of cloud grey level.

4. Environmental (ambient) radiation scatters off the cloud into the field of view (path radiance) contributing a factor that cannot be accounted for with the current tools used in ATLAS analyses.

5. Background scene radiance is not constant with time.

In spite of these limitations and the lack of *a priori* information that allows a predetermination of the success or failure of test support, most of the time viable products are provided to the customer, and the concomitant learning process improves future products.

2.4 Error Analyses

The derivation of the error analyses is based on standard error analyses procedures delineated by Beers [10] and applied in the CSU/Metsat reports. The errors in output transmittance are due to error propagation from the ATLAS algorithm input variables. Input to the error analyses equations are estimates of the error absolute standard deviation. For the purposes of discussion, the ATLAS algorithm is restated with different symbols used for the variables:

$$T = \frac{GLC - GLS}{GLB - GLS} = \frac{N_R - B}{N_C - B} \tag{5}$$

where

GLC = the grey level of the current pixel location at the current time
GLS = the grey level of the smoke cloud under optically thick conditions
GLB = the grey level of the current pixel at some time before smoke in clear air.

The analyses only apply to this algorithm. If the ATLAS algorithm is modified, the error analyses must be updated. If one or more of the basic assumptions is seriously violated, the error analyses are meaningless (because different relationships among the variables will exist).

A discussion of the error estimates for each of the variables in equation (4) follows. The error estimates of GLC are made from the determination of radiometer accuracy (nominally 0.5 K -- for the gain setting used in this example) and effects of multiple scattering. For an instrument dynamic range of $\Delta T = 10$ K, the estimate in grey level counts (for 8 bits dynamic range = 256 grey levels) is $\approx \pm 13$ counts. The scattering effects are $\approx \pm 4$ counts. [6] Therefore, an example of the absolute standard deviation of GLC is given by

$$s_{GLC} = \sqrt{4^2 + 13^2} = \pm\ 13.6\ counts \tag{6}$$

The error estimate for GLB is primarily determined from radiometer accuracy. A way to reduce this value is to average several N clear air frames:

$$N\ images \rightarrow \frac{1}{\sqrt{N}}(\pm 13) \tag{7}$$

(Significant averaging of frames to reduce s_{GLC} is not possible because the scene is dynamic during the presence of smoke and the averaging would wash out the dynamics of interest; however, there is some low-pass filtering required in the data reduction process to ensure that the results are presented without aliasing.)

The error estimate of GLS is derived from the procedures used to arrive at GLS. The best fit correlation can be used to produce a minimum absolute standard deviation; or an estimate of the scatter in the value can be made analytically or by eye. There may also be biases present in the determination of GLS because of the technique or some unaccounted for problem (such as stray path radiance). As better ways evolve to determine GLS, the error estimate should become more objective and, hopefully, smaller.

The calculation of the error needs to consider three separate cases because different procedures apply for each. The first is the case in which GLC ≠ GLS. Equation (4) is rewritten as

$$x = GLC - GLS \tag{8}$$

$$y = GLB - GLS \tag{9}$$

$$T = \frac{x}{y}. \tag{10}$$

The absolute standard deviations of the ATLAS variables are used by

$$s_x = \sqrt{s_{GLC}^2 + s_{GLS}^2} \tag{11}$$

$$s_y = \sqrt{s_{GLB}^2 + s_{GLS}^2}. \tag{12}$$

The relative standard deviation is

$$s_t = T\sqrt{\left(\frac{s_y}{y}\right)^2 + \left(\frac{s_x}{x}\right)^2}. \tag{13}$$

For the second case, GLC = GLS (T = 0 percent), equation (4) is rewritten as

$$x = \frac{GLC}{z} \tag{14}$$

$$y = \frac{GLS}{z} \tag{15}$$

$$z = GLB - GLS. \tag{16}$$

The absolute standard deviations of the ATLAS variables are used by

$$T = x - y \tag{17}$$

$$s_z = \sqrt{s_{GLB}^2 + s_{GLS}^2} \tag{18}$$

$$s_x = x\sqrt{\left(\frac{s_{GLC}}{GLC}\right)^2 + \left(\frac{s_z}{z}\right)^2} \tag{19}$$

$$s_y = y\sqrt{\left(\frac{s_{GLS}}{GLS}\right)^2 + \left(\frac{s_z}{z}\right)^2}. \tag{20}$$

The relative standard deviation for this case is

$$S_t = \sqrt{S_x^2 + S_y^2}. \tag{21}$$

For the third case, GLB = GLS, and the transmittance value is undefined; therefore, the error estimate S_T is also undefined.

A series of figures (2, 3, 4, and 5) is presented to show an input image, the resulting transmittance map, and the error map. The processing involves the application of equation (4) to each pixel in figures 2 and 3 to arrive at the map of figure 4. Each pixel in this series of images is processed with the error algorithms previously discussed to arrive at the error map of figure 5. An appreciation of the amount of processing required for a typical trial of 10 min duration is gained when it is realized that an 8-frame running average of the base video rate of 30 frames/s is performed, and every third frame is grabbed to provide 10 frames/s (low-pass filtering) for ATLAS processing, resulting in over 6000 images for further analysis.

In summary, if the basic ATLAS algorithm, equation (4), becomes modified, the error analyses must be updated. For example, when the imager is used to observe a target of opportunity or when a source is placed in the field of view (as is the case when the VORTEX* system [11] is implemented) and the Multipath Transmissometer Radiometer algorithm is used, a new set of equations must be developed. If any of the basic assumptions are violated, the output of the error analyses is meaningless.

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*VORTEX is an acronym for a transmissometer system consisting of an imager as a receiver and an array of sources configured on a tower so that multiple LOSs in the vertical dimension (as opposed to the more usual horizontal dimension) may be measured.

2.5 Mitigation Efforts

Efforts to mitigate violated assumptions or lessen the impact of the limitations have primarily only reached the discussion stage because it is felt that mitigation efforts may be so intensive at this stage of ATLAS development that they would unnecessarily slow progress and delivery of the product to the customer. However, what has been discussed, accomplished, or is in progress will be presented next.

Figure 2. A pretrial image from a typical smoke trial. This scene provides the GLB used in the ATLAS algorithm. Each pixel location provides its unique grey level.

Figure 3. An image of the scene of figure 2 with smoke present. The grey level array provides the GLCs for equation (4).

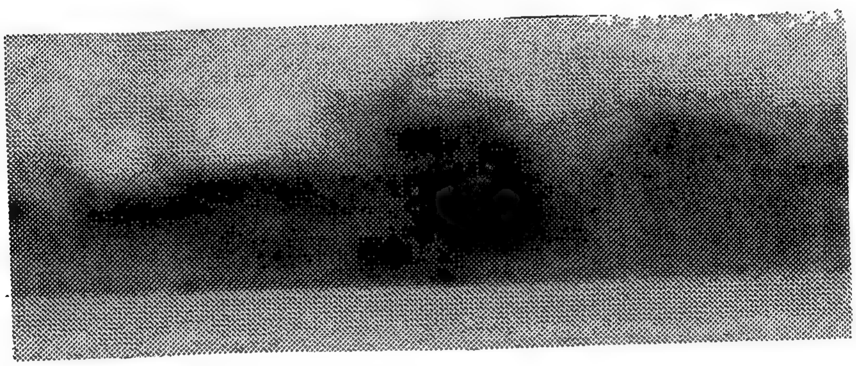

Figure 4. The transmittance map (transmittance in percent is proportional to grey level -- 0 percent is black and 100 percent is light grey) that results from the ATLAS processing of the images in figures 2 and 3. The cloud grey level, GLS, is a global constant and the same value applies everywhere in the image; therefore, there is no GLS image to correspond to those for GLC and GLB.

Figure 5. The error map that results from the application of the error analyses to this example shown in figures 2, 3, and 4. (Black is 0 percent error and white is equal to or greater than 243 percent error.) In theory, such a map should be provided with each transmittance image; in practice, only regions of large uncertainty are identified at the current time even though the capability exists to do the full analyses.

Two efforts are under way to understand and mitigate the limitation imposed by the temporal variation of the background radiance. To begin with, experience in the field has indicated that this may not be as severe a problem as one might think. On days of variable cloudiness, for example, the background radiance changes and instances of rapid fluctuations were observed; with no apparent cause. An example of this last situation is given by figure 6, which is a plot of grey level with time for a portion of a background scene observed in 1989. This observation was made under the following conditions:

- Time of day was approximately noon.
- Skies were clear (no clouds or haze).
- Location was Oscura Range ($\approx$ 7000 ft elevation) (White Sands Missile Range (WSMR), NM).
- Transmissometers were positioned along the LOS.
- Visible videos in black and white and color were recorded.

From these conditions and observations (transmissometers and video observations indicated no changes from clear air conditions at the location with high altitude and clear, dry air at WSMR) it was concluded that there were no atmospheric fluctuations that could have caused the variation in background radiance. In addition, the variations were seen only in a portion of the image; therefore, it was not an imager problem. It is believed that the wind blowing up an arroyo caused changes in the transpiration and/or orientation of leaf structure of the vegetation, which caused a change in apparent radiance. In an attempt to better understand this type of problem and to assess its importance, a program of monitoring a local background scene at WSMR has been in place for about one and a half years. As part of this program, an environmental survey of the scene was conducted, and the tools necessary to reduce and understand the observations were obtained and developed. Two publications were produced by the effort. [12,13]

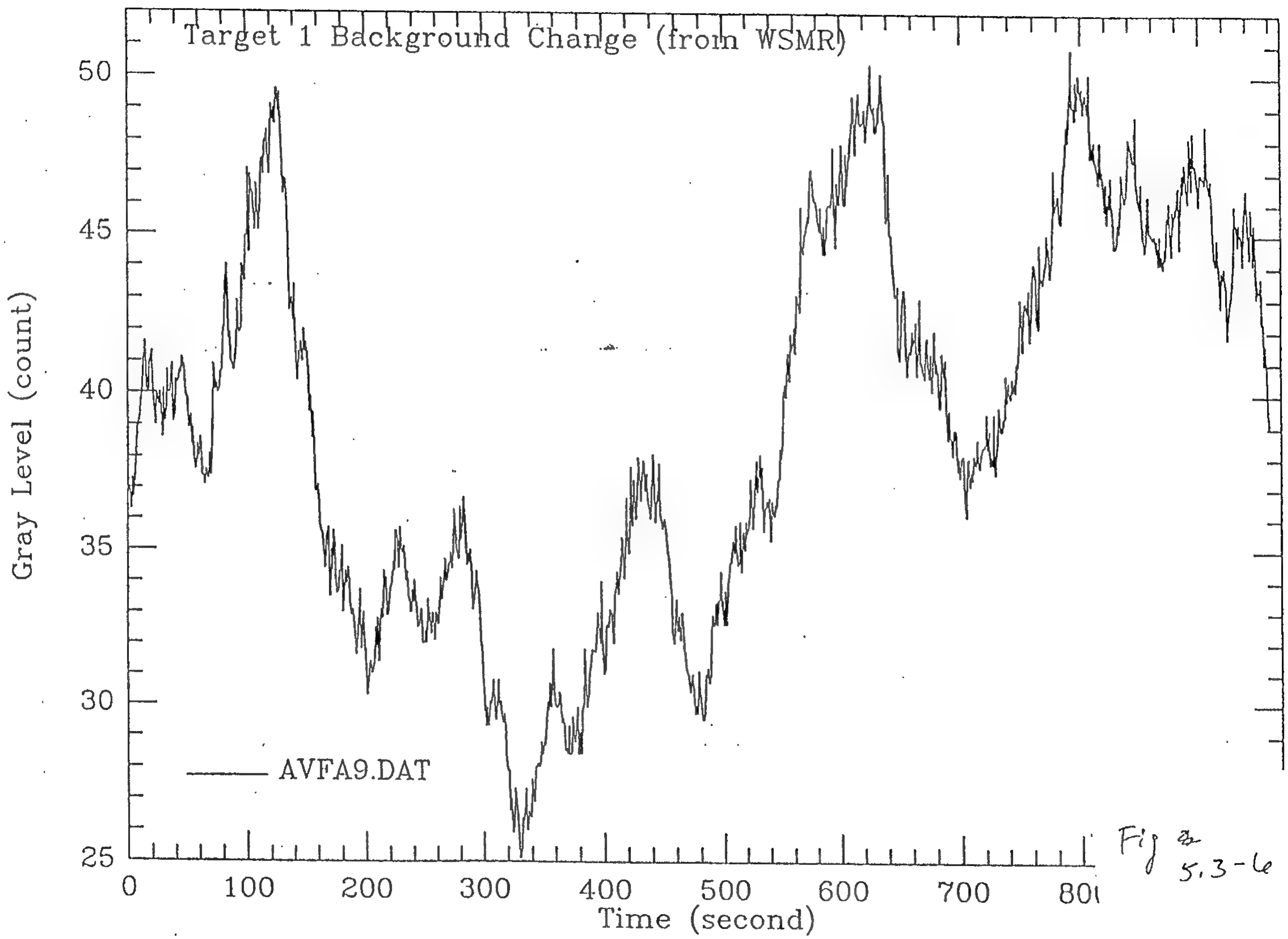

Figure 6. Rapid and large fluctuations in background radiance.

The other effort to mitigate variations in the background radiance is to use a millimeter wave (MMW) imaging system to observe the background radiance through visual and IR smokes and obscurants (note variations in radiance at MMW frequencies) and use the equations and models discussed to correct the IR radiance. This would serve another purpose; the imaging system could be used for ATLAS processing of MMW obscurants. The progress with this effort has been slow because of priorities. The receiver components and an antenna sufficient for single LOS observations were obtained and assembled. The next level of effort is to develop a scanning system for the radiometer so it can operate in an imaging mode. When fully developed, this system and follow-on systems will be useful for conducting scene radiance studies at MMW frequencies, characterizing MMW smokes and obscurants, and developing inclement weather surveillance systems. (Such systems could be placed in remotely piloted vehicles.)

Cloud radiance problems manifest themselves in two ways: in the determination of GLC and in which GLC is the same or nearly the same as the background radiance. The determination of GLC relies on a variety of intensive and interactive techniques. Efforts are underway to analyze the library of GLCs acquired to date to determine whether a more successful way of arriving at GLC, *a priori*, may be found. The problem of dynamic range GLC $\approx$ GLB, may be overcome through judicious use of high-gain measurements; although, this will not work in all cases. A way around this is to estimate transmittance values in the region of uncertainty by using values from a nearby region and taking into account cloud movement; cloud structure remains sufficiently unchanged over small changes in time. As the situations that create this problem are better understood, test setup can be modified to eliminate the problem (observing from a different perspective to allow a different background).

When it is known that for a particular observation situation that scattering of environmental radiation by the cloud will affect the measurement, or that the cloud is self-emissive, use of sources in the field of view (see the VORTEX system description [11]) can allow modified ATLAS measurements. Use of VORTEX may allow a quantitative estimate of these effects so the error estimates may be properly made. Multispectral observations may identify scattering phenomena and, thus, assist in mitigation. Most of this is purely speculative; however, it holds promise for further development of ATLAS.

3. Conclusions

It has become more usual to discuss verification, validation, and accreditation, in particular, as applied to models. A presentation given at a recent Smoke/Obscurants Symposium, [14] defined these words to mean the following (paraphrased):

verification: (happens first)	Does the model do what is expected; is arithmetic correct?
validation:	Does the model replicate what goes on in nature; how close?
accreditation:	Stamp of approval by the organization using or making the model that it has been verified and validated for a specific application and the conditions for which it was verified and validated.

In the context of what is presented in this report, all three of these processes have been completed and are documented here and discussed without discrimination as to the specific category (verification, validation, or accreditation) under scrutiny. The reason for using validation in generic terms has more to do with the accomplishment of a goal than a restriction of effort. Specifically, the verification process was the work accomplished by Vonder Haar and associates. The validation is the comparison of ATLAS data with more conventional transmissometer measurements in which the differences (basically, there are none) have been quantified and reported in two of the papers listed in the reference section. [8,9] Accreditation can include the portion of the previous discussion that describes the assumptions underlying the technique and the resulting limitation that this places on the use of ATLAS.

The ATLAS technique is continually under further development. With each new test situation, more is learned and improvements are made. ATLAS has been used to support numerous field tests and has been a key measurement for characterization of smoke/obscurant clouds. The documentation presented here shows ATLAS to be a viable process of which the full potential remains to be utilized.

References

1. Bleiweiss, M. P., R. A. Howerton, K. C. Payne, and T. A. King, "New Technique for Visualizing Three-Dimensional Flow in the Atmospheric Boundary Layer." In *Flow Visualization VI: Proceedings of the Sixth International Symposium on Flow Visualization*, Yokohama, Japan, Y. Tanida and H. Miyashiro (Eds.), Springer-Verlag Berlin Heidelberg, 1992.

2. Bleiweiss, M. P., K. C. Payne, and T. A. King, "CIRRUS: Real Smoke Clouds for Simulations and Simulators." In *Proceedings of the Smoke/Obscurant Symposium XVII*, U.S. Army Research Laboratory, WSMR, NM, 1993.

3. Alongi, R. E., Private communication, 1992.

4. Vonder Haar, T., G. Stephens, A. Jones, C. F. Shih, and J. Davis, *Analysis and Assessment of the Atmospheric Transmittance Large Area System (ATLAS)*, Final Report, Metsat, Inc., Fort Collins, CO, January 1990.

5. Vonder Haar, T., A. Jones, T. Wong, and C. Combs, *Extension and Implementation of Error Analysis Techniques Developed for the Atmospheric Transmission Large Area System (ATLAS)*, Final Report, Metsat, Inc., Fort Collins, CO, 15 February 1992.

6. Jones, A. S., T. H. Vonder Haar, and M. P. Bleiweiss, "An Assessment of an Infrared Imager Transmittance Measurement System." In *Proceedings of the Smoke/Obscurants Symposium XV*, U.S. Army Chemical Research Development and Engineering Center, Aberdeen Proving Ground, MD, April 1991.

7. Jones, A. S., C. L. Combs, and T. H. Vonder Haar, *Atmospheric Transmittance Large Area System (ATLAS) Transmittance Error Analysis Algorithm*, Metsat, Inc., Fort Collins, CO, 15 February 1992.

8. Bleiweiss, M., R. Howerton, R. Valdez, K. Payne, T. King, and K. Hutchison, "Comparison of the MPTR and ATLAS Transmissometers." In *Proceedings of the 11th Annual EOSAEL/TWI Conference*, U.S. Army Atmospheric Sciences Laboratory, WSMR, NM, 1990.

9. Bleiweiss, M., R. Howerton, R. Valdez, K. Payne, T. King, and K. Hutchison, "Comparison of the MPTR and ATLAS Transmissometers." In *Proceedings of the Smoke/Obscurant Symposium XV*, U.S. Army Chemical Research Development and Engineering Center, Aberdeen Proving Ground, MD, April 1991. (This was an expanded version of the EOSAEL/TWI paper of the same name.)

10. Beers, Y., *Introduction to the Theory of Errors*, Addison-Wesley Publishing Co., Inc., Reading, MA, 1957.

11. Bleiweiss, M. P., R. E. Davis, T. A. King, and K. C. Payne, "VORTEX: A New Tool for Observing Vertical Structure of Smoke/Obscurant Clouds." In *Proceedings of the 1992 Battlefield Atmospherics Conference*, U.S. Army Research Laboratory, WSMR, NM, 1992.

12. Nolen, B. and D. D. Bustamante, *A Review of Thermal Models and Site Data for the High Temporal Resolution Characterization of Natural Terrain Radiance Fluctuations at the MIDAS/ATLAS Site*, PSL-91/46, Physical Science Laboratory, New Mexico State University, Las Cruces, NM, October 1991.

13. Bustamante, D. D. and B. Nolen, *A Bibliography of Models and Model Parameters for Multispectral Remote Sensing at the MIDAS/ATLAS Site*, PSL-91/53, Physical Science Laboratory, New Mexico State University, Las Cruces, NM, October 1991.

14. O'Bryon, J. F., "Model Validation, Verification, and Accreditation (VVA)." In *Proceedings of the Smoke/Obscurants Symposium XVII*, U.S. Army Chemical and Biological Defense Agency, Aberdeen Proving Ground, MD, October 1993.

Acronyms and Abbreviations

ARL	Army Research Laboratory
ATLAS	Atmospheric Transmission Large-Area Analysis System
CSU	Colorado State University
IR	infrared
LOS	line of sight
MMW	millimeter wave
WSMR	White Sands Missile Range

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ARMY MISSILE CMND AMSMI RD AC AD ATTN DR PETERSON REDSTONE ARSENAL AL 35898-5242	1
ARMY MISSILE CMND AMSMI RD AS SS ATTN MR H F ANDERSON REDSTONE ARSENAL AL 35898-5253	1
ARMY MISSILE CMND AMSMI RD AS SS ATTN MR B WILLIAMS REDSTONE ARSENAL AL 35898-5253	1

ARMY MISSILE CMND 1
AMSMI RD DE SE
ATTN MR GORDON LILL JR
REDSTONE ARSENAL
AL 35898-5245

ARMY MISSILE CMND 1
REDSTONE SCI INFO CTR
AMSMI RD CS R DOC
REDSTONE ARSENAL
AL 35898-5241

ARMY MISSILE CMND 1
AMSMI
REDSTONE ARSENAL
AL 35898-5253

ARMY INTEL CTR 1
AND FT HUACHUCA
ATSI CDC C
FT HUACHUCA AZ 85613-7000

NORTHROP CORPORATION 1
ELECTR SYST DIV
ATTN MRS T BROHAUGH
2301 W 120TH ST BOX 5032
HAWTHORNE CA 90251-5032

NAVAL WEAPONS CTR 1
CODE 3331
ATTN DR SHLANTA
CHINA LAKE CA 93555

PACIFIC MISSILE TEST CTR 1
GEOPHYSICS DIV
ATTN CODE 3250
POINT MUGU CA 93042-5000

LOCKHEED MIS & SPACE CO 1
ATTN KENNETH R HARDY
ORG 91 01 B 255
3251 HANOVER STREET
PALO ALTO CA 94304-1191

NAVAL OCEAN SYST CTR 1
CODE 54
ATTN DR RICHTER
SAN DIEGO CA 92152-5000

METEOROLOGIST IN CHARGE 1
KWAJALEIN MISSILE RANGE
PO BOX 67
APO SAN FRANCISCO
CA 96555

DEPT OF COMMERCE CTR 1
MOUNTAIN ADMINISTRATION
SPPRT CTR LIBRARY R 51
325 S BROADWAY
BOULDER CO 80303

DR HANS J LIEBE 1
NTIA ITS S 3
325 S BROADWAY
BOULDER CO 80303

NCAR LIBRARY SERIALS 1
NATL CTR FOR ATMOS RSCH
PO BOX 3000
BOULDER CO 80307-3000

DEPT OF COMMERCE CTR 1
325 S BROADWAY
BOULDER CO 80303

DAMI POI 1
WASH DC 20310-1067

MIL ASST FOR ENV SCI OFC 1
OF THE UNDERSEC OF DEFNS
FOR RSCH & ENGR R&AT E LS
PENTAGON ROOM 3D129
WASH DC 20301-3080

DEAN RMD 1
ATTN DR GOMEZ
WASH DC 20314

SPACE NAVAL WARFARE SYST CMND PMW 145 1G WASH DC 20362-5100	1
ARMY INFANTRY ATSH CD CS OR ATTN DR E DUTOIT FT BENNING GA 30905-5090	1
AIR WEATHER SERVICE TECH LIBRARY FL4414 3 SCOTT AFB IL 62225-5458	1
USAFETAC DNE ATTN MR GLAUBER SCOTT AFB IL 62225-5008	1
HQ AWS DOO 1 SCOTT AFB IL 62225-5008	1
ARMY SPACE INSTITUTE ATTN ATZI SI 3 FT LEAVENWORTH KS 66027-5300	1
PHILLIPS LABORATORY PL LYP ATTN MR CHISHOLM HANSCOM AFB MA 01731-5000	1
ATMOSPHERIC SCI DIV GEOPHYSICS DIRCTRT PHILLIPS LABORATORY HANSCOM AFB MA 01731-5000	1
PHILLIPS LABORATORY PL LYP 3 HANSCOM AFB MA 01731-5000	1

RAYTHEON COMPANY ATTN DR SONNENSCHEIN 528 BOSTON POST ROAD SUDBURY MA 01776 MAIL STOP 1K9	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY ATTN MP H COHEN APG MD 21005-5071	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY AT ATTN MR CAMPBELL APG MD 21005-5071	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY CR ATTN MR MARCHET APG MD 21005-5071	1
ARL CHEMICAL BIOLOGY NUC EFFECTS DIV AMSRL SL CO APG MD 21010-5423	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY APG MD 21005-5071	1
NAVAL RESEARCH LABORATORY CODE 4110 ATTN MR RUHNKE WASH DC 20375-5000	1
ARMY MATERIEL SYST ANALYSIS ACTIVITY AMXSY CS ATTN MR BRADLEY APG MD 21005-5071	1

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TECHNICAL PUBLISHING
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2800 POWDER MILL ROAD
ADELPHI MD 20783-1145 1

ARMY RESEARCH LABORATORY
AMSRL SS SH
ATTN DR SZTANKAY
2800 POWDER MILL ROAD
ADELPHI MD 20783-1145 1

ARMY RESEARCH LABORATORY
AMSRL
2800 POWDER MILL ROAD
ADELPHI MD 20783-1145 1

NATIONAL SECURITY AGCY W21
ATTN DR LONGBOTHUM
9800 SAVAGE ROAD
FT GEORGE G MEADE
MD 20755-6000 1

ARMY AVIATION CTR
ATZQ D MA
ATTN MR HEATH
FT RUCKER AL 36362 1

OIC NAVSWC
TECH LIBRARY CODE E 232
SILVER SPRINGS
MD 20903-5000 1

ARMY RSRC OFC 1
ATTN DRXRO GS
PO BOX 12211
RTP NC 27009

DR JERRY DAVIS 1
NCSU
PO BOX 8208
RALEIGH NC 27650-8208

ARMY CCREL 1
CECRL GP
ATTN DR DETSCH
HANOVER NH 03755-1290

ARMY ARDEC 1
SMCAR IMI I BLDG 59
DOVER NJ 07806-5000

ARMY COMMUNICATION 1
ELECTR CTR FOR EW RSTA
AMSEL RD EW SP
FT MONMOUTH NJ 07703-5206

ARMY SATELLITE COMM AGCY 1
DRCPM SC 3
FT MONMOUTH NJ 07703-5303

ARMY COMMUNICATIONS 1
ELECTR CTR FOR EW RSTA
AMSEL EW D
FT MONMOUTH NJ 07703-5303

ARMY COMMUNICATIONS 1
ELECTR CTR FOR EW RSTA
AMSEL EW MD
FT MONMOUTH NJ 07703-5303

ARMY DUGWAY PROVING GRD 1
STEDP MT DA L 3
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GRD STEDP MT M ATTN MR BOWERS DUGWAY UT 84022-5000	1
DEPT OF THE AIR FORCE OL A 2D WEATHER SQUAD MAC HOLLOMAN AFB NM 88330-5000	1
PL WE KIRTLAND AFB NM 87118-6008	1
USAF ROME LAB TECH CORRIDOR W STE 262 RL SUL 26 ELECTR PKWY BLD 106 GRIFFISS AFB NY 13441-4514	1
AFMC DOW WRIGHT PATTERSON AFB OH 0334-5000	1
ARMY FIELD ARTLLRY SCHOOL ATSF TSM TA FT SILL OK 73503-5600	1
NAVAL AIR DEV CTR CODE 5012 ATTN AL SALIK WARMINISTER PA 18974	1
ARMY FOREGN SCI TECH CTR CM 220 7TH STREET NE CHARLOTTESVILLE VA 22901-5396	1
NAVAL SURFACE WEAPONS CTR CODE G63 DAHLGREN VA 22448-5000	1

ARMY OEC
CSTE EFS
PARK CENTER IV
4501 FORD AVE
ALEXANDRIA VA 22302-1458 1

ARMY CORPS OF ENGRS
ENGR TOPOGRAPHICS LAB
ETL GS LB
FT BELVOIR VA 22060 1

TAC DOWP
LANGLEY AFB
VA 23665-5524 1

ARMY TOPO ENGR CTR
CETEC ZC 1
FT BELVOIR VA 22060-5546 1

LOGISTICS CTR
ATCL CE
FT LEE VA 23801-6000 1

SCI AND TECHNOLOGY
101 RESEARCH DRIVE
HAMPTON VA 23666-1340 1

ARMY NUCLEAR CML AGCY
MONA ZB BLDG 2073
SPRINGFIELD VA 22150-3198 1

ARMY FIELD ARTLLRY SCHOOL
ATSF F FD
FT SILL OK 73503-5600 1

USATRADOC
ATCD FA
FT MONROE VA 23651-5170 1

ARMY TRADOC ANALYSIS CTR
ATRC WSS R
WSMR NM 88002-5502 1

ARMY RESEARCH LABORATORY AMSRL BE M BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE A BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE W BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE ATTN MR VEAZEY BATTLEFIELD ENVIR DIR WSMR NM 88002-5501	1
DEFNS TECH INFO CTR CENTER DTIC BLS BLDG 5 CAMERON STATION ALEXANDRIA VA 22304-6145	1
ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL FT MONMOUTH NJ 07703-5303	1
ARMY MISSILE CMND AMSMI REDSTONE ARSENAL AL 35898-5243	1
ARMY DUGWAY PROVING GRD STEDP 3 DUGWAY UT 84022-5000	1

ARMY COMMUNICATIONS ELECTR CTR FOR EW RSTA AMSEL FT MONMOUTH NJ 07703-5206	1
USATRADOC ATCD FA FT MONROE VA 23651-5170	1
ARMY FIELD ARTLRY SCHOOL ATSF FT SILL OK 73503-5600	1
WSMR TECH LIBRARY BR STEWS IM IT WSMR NM 88001	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R LAUGHMAN APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR W G KLIMEK APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR A VAN DE WAL APG MD 21010-5423	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R HOWERTON WSMR NM 88002	1
ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR R DE KINDER WSMR NM 88002	1

ARMY RESEARCH LABORATORY AMSRL SL CO ATTN MR J E BUTTERFIELD WSMR NM 88002	1
MR J SERNA NMSU PSL LAS CRUCES NM 88003	1
MS J ESPARZA NMSU PSL LAS CRUCES NM 88003	1
MR D STOGDEN NMSU PSL LAS CRUCES NM 88003	1
MR T KING NMSU PSL LAS CRUCES NM 88003	1
MR K PAYNE NMSU PSL LAS CRUCES NM 88003	1
DR THOMAS VONDER HAAR STC METSAT 515 SOUTH HOWES STREET FORT COLLINS CO 80521	1
ARMY RESEARCH LABORATORY AMSRL BE S ATTN DR D HOOCK WSMR NM 88002-5501	1
ARMY RESEARCH LABORATORY AMSRL BE S ATTN DR J GILLESPIE WSMR NM 88002-5501	1

ARMY RESEARCH LABORATORY 1
AMSRL BE E
ATTN DR D GARVEY
WSMR NM 88002-5501

ARMY RESEARCH LABORATORY 1
AMSRL BE S
ATTN DR R SHIRKEY
WSMR NM 88002-5501

ARMY EDGEWOOD RESEARCH 1
DEV AND ENGIN CTR
SCBRD CE
ATTN MS C KILGORE WOLF
APG MD 21010-5423

ARMY EDGEWOOD RESEARCH 1
DEV AND ENGIN CTR
SCBRD CE
ATTN MR J MOORE
APG MD 21010-5423

ARMY EDGEWOOD RESEARCH 1
DEV AND ENGIN CTR
SCBRD RT
ATTN MR D PRAPAS
APG MD 21010-5423

PROJECT MANAGER 1
SMOKES AND OBSCURANTS
AMCPM SM
APG MD 21010-5423

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SCBRD EN
ATTN MR R RHEA
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SCBRD EN
ATTN MR WILLIAM G. ROUSE
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MR BENJAMIN PERRY IV GEORGIA TECH RES INSTITUTE BLDG 5 108 7220 RICHARDSON RD SMYRNA GA 30080	1
MR MARK PERRY BATTELLE 505 KING AVENUE COLUMBUS OH 43201	1
MR G BLACKMAN 1455 TIERRA DEL SOL DRIVE LAS CRUCES NM 88005	1
DR R DAVIS SCIENCE AND TECHNOLOGY CORP 555 S TELSHOR BLVD SUITE 200 LAS CRUCES NM 88011	1
HQ TEST AND EXPER CMND CSTE TES ATTN MR RICK JERNIGAN FORT HOOD TX 76544-5065	1
DR W MICHAEL FARMER THE INCA GROUP FNB SUITE 900 500 S MAIN LAS CRUCES NM 88001	1
MR R STOUT OPTIMETRICS INC 2107 LAUREL BUSH ROAD SUITE 209 BEL AIR MD 21015	1
HQDA SAUS OR ATTN DR ROBERT HINKLE THE PENTAGON 1E643 WASHINGTON DC 20310-0102	1

DR JOHN MOLITARIS 1
LAWRENCE LIVERMORE NATL LAB
PO BOX 808 MS L 262
LIVERMORE CA 94550

ARMY DUGWAY PROVING GROUND 1
STEDP WD TS AV
ATTN MR J YALE
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GROUND 1
STEDP WD TM MO
ATTN MR D BODRERO
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GROUND 1
STEDP WD TM
ATTN MR L CARTER
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GROUND 1
STEDP WD M
ATTN MR C BILTOFT
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GROUND 1
STEDP WD TS
ATTN MR W DWYER
DUGWAY UT 84022-5000

ARMY DUGWAY PROVING GROUND 1
STEDP WD M
ATTN MR J BOWERS
DUGWAY UT 84022-5000

MR R BERGER 1
ARMY COLD REGIONS RESEARCH
AND ENGINEERING LABORATORY
72 LYME ROAD
HANOVER NH 03755

PROJECT MANAGER NBC DEFENSE SYSTEMS AMCPM NN APG MD 21010-5423	1
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